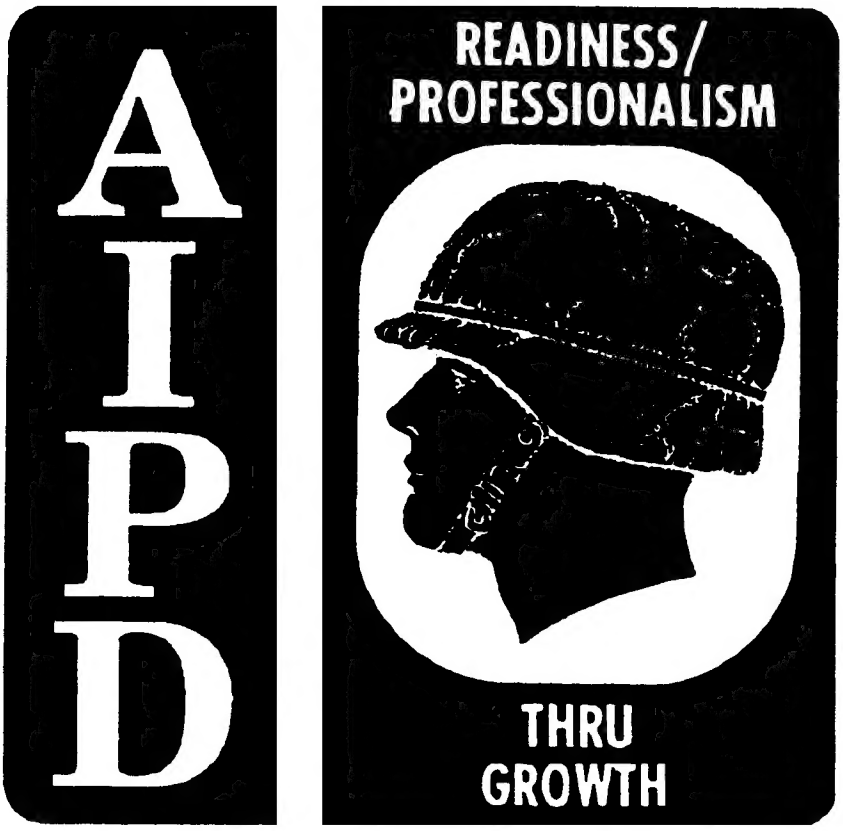
SUBCOURSE	EDITION
MM0327	6

FREQUENCY SYNTHESIS



THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM

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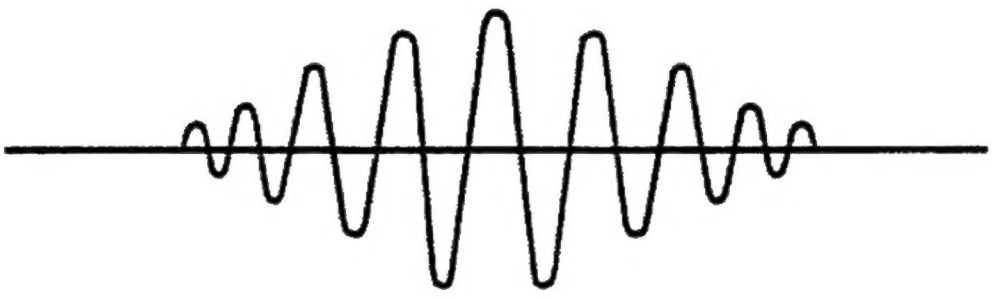

SUBCOURSE 327, FREQUENCY SYNTHESIS

INTRODUCTION

Radio communication is successful only when the communicators share the frequency spectrum and when they respect the frequency channel of every other communicator. Both of these operating requirements are best served by the use of frequency synthesizers.

As the name implies, a frequency synthesizer develops secondary frequencies from primary sources. These secondary frequencies may be developed through selecting harmonics, heterodyning harmonics, or heterodyning two stable frequencies to create a third. Moreover, the stability of the synthesized frequencies will be no better than the stability of the source frequencies.

Since many radio transmitters and receivers used in operating nets contain compatible frequency synthesizers, all communicators should understand their operation. This subcourse gives you the fundamental concepts of frequency synthesis with a block diagram analysis of different types of synthesizers.

This subcourse consists of two lessons and an examination, as follows:

Lesson 1. Introduction to Frequency Synthesis

Lesson 2. Classes of Synthesizers

Examination

Credit Hours: 5

You are urged to finish this subcourse without delay; however, there is no specific limitation on the time you may spend on any lesson or the examination.

Texts and materials furnished:

Subcourse Booklet

EXAMINATION AND RESPONSE SHEET.

You may keep the texts and materials furnished.

PLEASE NOTE

Proponency for this subcourse has changed from Signal (SS) to Missile & Munitions (MM).

LESSON 1

INTRODUCTION TO FREQUENCY SYNTHESIS

SCOPE	What frequency synthesis means; basic frequency synthesis principle; synthesizing methods; why synthesized output signals must be stabilized.
CREDIT HOURS	2
TEXT ASSIGNMENT	Attached Memorandum
MATERIALS REQUIRED	None
SUGGESTIONS	None

LESSON OBJECTIVES

When you have completed this lesson, you should:

1. Know that to prevent channel interference each carrier signal must be of a different frequency and extremely stable.

2. Know that frequency synthesis refers to the process of obtaining several different frequencies either from a single source or from a minimum number of sources.

3. Be able to identify the three general methods of synthesizing signals.

4. Know that a stabilized master oscillator (SMO) is controlled not only by a crystal, but also by special frequency-controlling circuits.

5. Be able to identify the two most common methods of stabilizing the SMO.

6. Know that most frequency-synthesizing circuits are made up of circuits that add, subtract, multiply, or divide the frequency of the signal applied to the input.

1-1. GENERAL INFORMATION

a. Modern multichannel communication equipment requires many different signal voltages to process the intelligence being transmitted. For example, to transmit voice signals over a multichannel system, each channel modulator must be supplied with a carrier signal. And to prevent channel interference, each of the carrier signals must be a different frequency and extremely stable.

b. In addition to the carrier signals, a system may also require signal voltages for testing, alarms, ringing, and synchronization. The methods used to produce these various signals may vary--it depends on the specific requirements. From the standpoint of economy and space, however, the most practical is a method called frequency synthesis.

1-2. WHAT FREQUENCY SYNTHESIS MEANS

The word synthesis is derived from the word synthetic, which means artificial, not original, or not genuine. Synthesis on the other hand means a composition, or combination of parts (elements) that form a whole. It follows then that frequency synthesis must refer to the process of obtaining several different synthetic frequencies either from a single frequency source or from a minimum number of sources.

1-3. BASIC FREQUENCY SYNTHESIS PRINCIPLE

a. To produce a synthesized signal, all you have to do is apply two signals of different frequencies to a non-linear device. For example, if you apply a 1 kiloHertz (kHz) signal an a 3 kHz signal to the modulator shown in figure 1, you get the following output signals.

(1) 1 kHz.

(2) 2 kHz.

(3) 3 kHz.

(4) 4 kHz.

b. The 2 kHz and the 4 kHz signals are the synthesized signals, and the other two signals are, of course, the two original signals. b other words, a synthesized signal is nothing more than the upper or lower sideband output from a modulating device. This is the same principle used in communication equipment to develop all the various signals that are needed to make the equipment work properly.

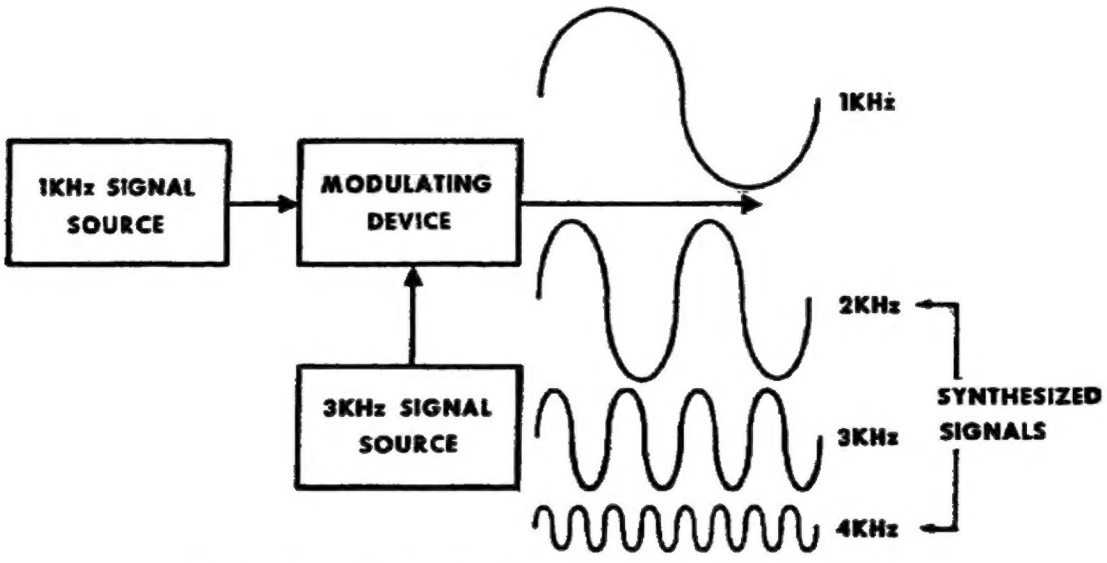

Figure 1. Basic frequency synthesis principle.

1-4. SYNTHESIZING METHODS

a. There are several different methods, or combinations of methods that produce synthesized signals. But, all of these methods are divided into three general classes as follows:

(1) Basic Modulation Method. This method is the same method shown in figure 1. It uses conventional modulating devices, such as electron tubes, transistors, or varistors.

(2) Harmonic Generation Method. Produces two or more signals from the same source, then modulates these signals to produce a large number of noise free synthesized signals. The modulator in this case is identical to the one described above.

(3) Heterodyne Method. Produces a single synthesized signal. All spurious and unwanted frequencies are suppressed by using the heterodyning principle as a filtering process.

b. The method, or combination of methods used in a specific application depends on the requirement. For example, if a large number of signals are required, chances are the harmonic generation method is used. If a harmonic and noise free signal is required then the heterodyne method is used. Some applications require many fixed signals, such as telephone multiplex equipment. In these cases the harmonic generation is used to great advantage. Other applications require variable output signals, as in radio transmitters and receivers. In these cases any or all three methods may be used, but one or both original signal sources must be adjustable.

1-5. HOW THE BASIC MODULATION METHOD WORKS

The basic modulation method is exactly the same process that uses voice to modulate a carrier signal as shown by the block diagram in figure 2. The output signals, as you know, depend on the input signals and whether the modulator is balanced or unbalanced. For example, if the signals into a balanced modulator are 1 kHz and 3 kHz, then there are only two output signals--2 kHz and 4 kHz (A, fig 2). However, if the original signals are applied to an unbalanced modulator, you get four signals at the output. In this case these signals are 1 kHz, 2 kHz, 3 kHz, and 4 kHz (B, fig 2).

1-6. HOW THE HARMONIC GENERATION METHOD WORKS

a. To generate harmonics, you must apply the fundamental frequency to a nonlinear device. A common method is to apply the signal to an electron tube biased to operate as a class b or a class c amplifier.

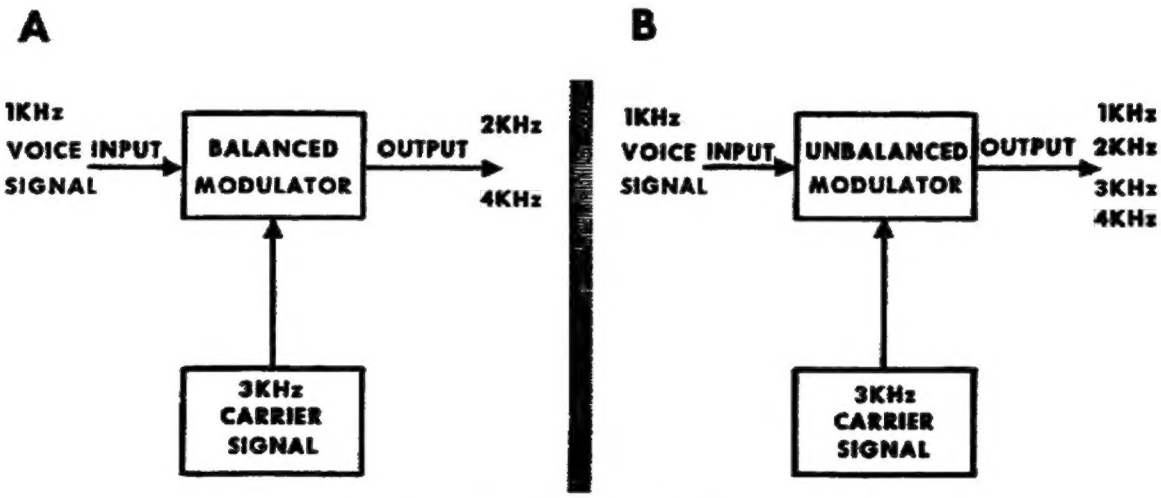

Figure 2. Basis modulation method.

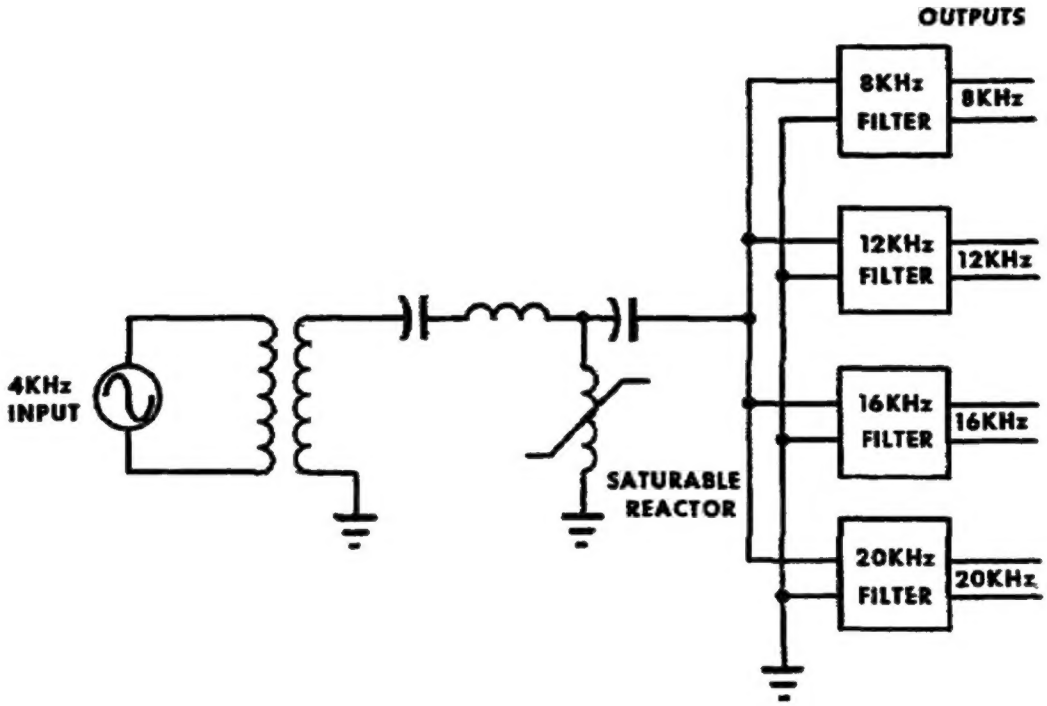

Figure 3. Harmonic generating circuit.

Another common method is to apply the fundamental signal to a specially designed coil called a saturable reactor. The symbol of this component is shown in figure 3.

b. When a signal is applied to these non-linear devices, the output is rich in harmonics. Each of the harmonics is separated from each other by the value of the original signal. For example, the harmonics of a 4 kHz signal are; 8 kHz, 12 kHz, 16 kHz, and so on. The desired signals are selected by filter circuits as shown in figure 3. The selected signals, in turn, can develop additional signals if they are applied to a modulating circuit as shown in figure 4.

c. Another method of generating harmonics is to generate rectangular (square) waves because they are rich in odd harmonics. One technique is to make a signal source control the operation of a multivibrator so that the output is a predetermined frequency. The output of the multivibrator is then filtered to get the various desired output signals, as shown in figure 5.

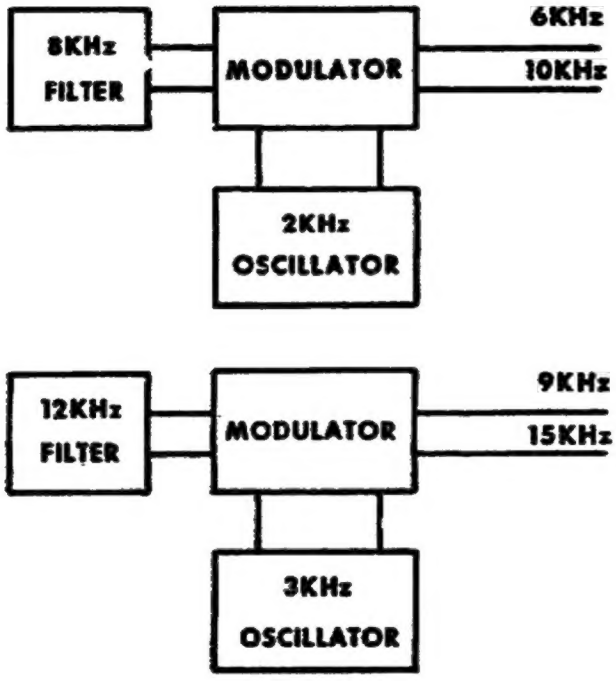

Figure 4. One source can produce many signals.

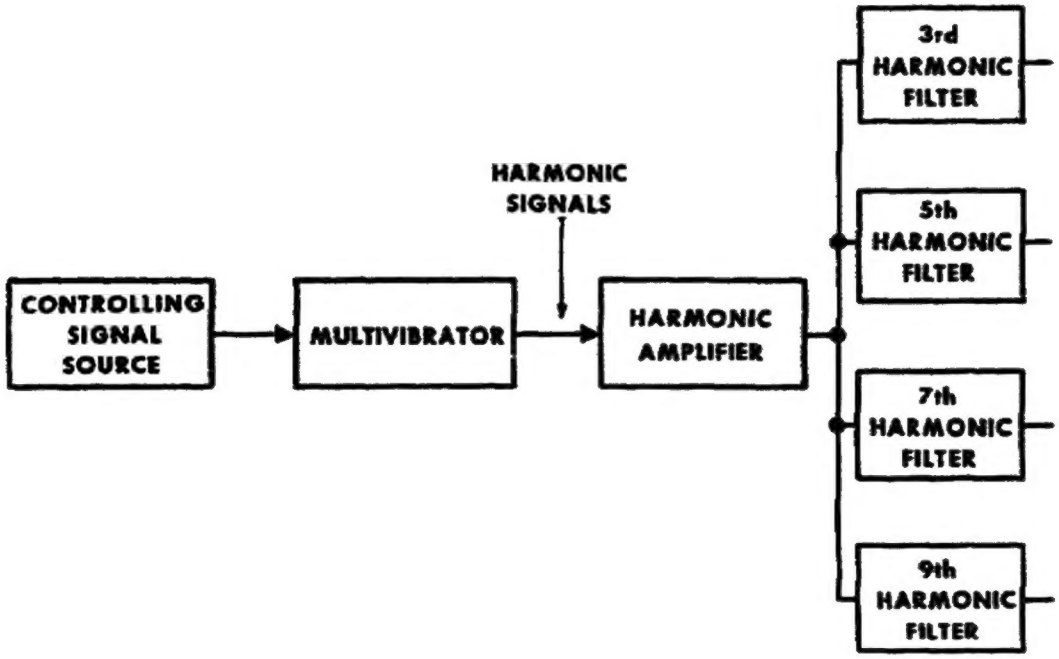

Figure 5. Harmonic generating using a multivibrator.

1-7. HOW THE HETERODYNE METHOD WORKS

a. The heterodyning process is a modulation process. When it is used in a frequency synthesizing circuit, it serves as a filtering process as well. A typical circuit that uses heterodyning to synthesize frequencies is shown in figure 6.

b. Notice that the circuit in figure 6 is divided into three sections.

(1) Harmonic generating section.

(2) Filtering section.

(3) Output section.

c. The harmonic generating section works similarly to the circuit shown in figure 5. The filtering section is divided into two parts--a variable filter circuit and a heterodyning circuit. The filter selects one of the harmonics and the heterodyning circuit purifies this signal so that no other harmonic, or any of the harmonic by-products, get to the output section To do this, the selected harmonic signal is modulated with a carrier signal. The frequency of the carrier must be such a value that the output of the first mixer is 400 kHz. For example, to make the lower sideband signal output from the first mixer 400 kHz when the input 2.54 MHz, the carrier oscillator must produce 2.14 MHz, as shown by the following calculations.

2,540,000 - 2,140,000 = 400,000

Then, to insure that the output signal from the first mixer is actually 400 kHz critical filter circuits are connected to the input and output of the 400 kHz amplifier. This 400 kHz signal then modulates the same carrier signal that is modulated by the selected 2.54 MHz harmonic signal. This second modulation process produces a sideband signal that is exactly equal to the original 2.54 MHz harmonic signal. The difference between this output signal and the original harmonic signal is that the output signal is free from all harmonics, noise and spurious signals.

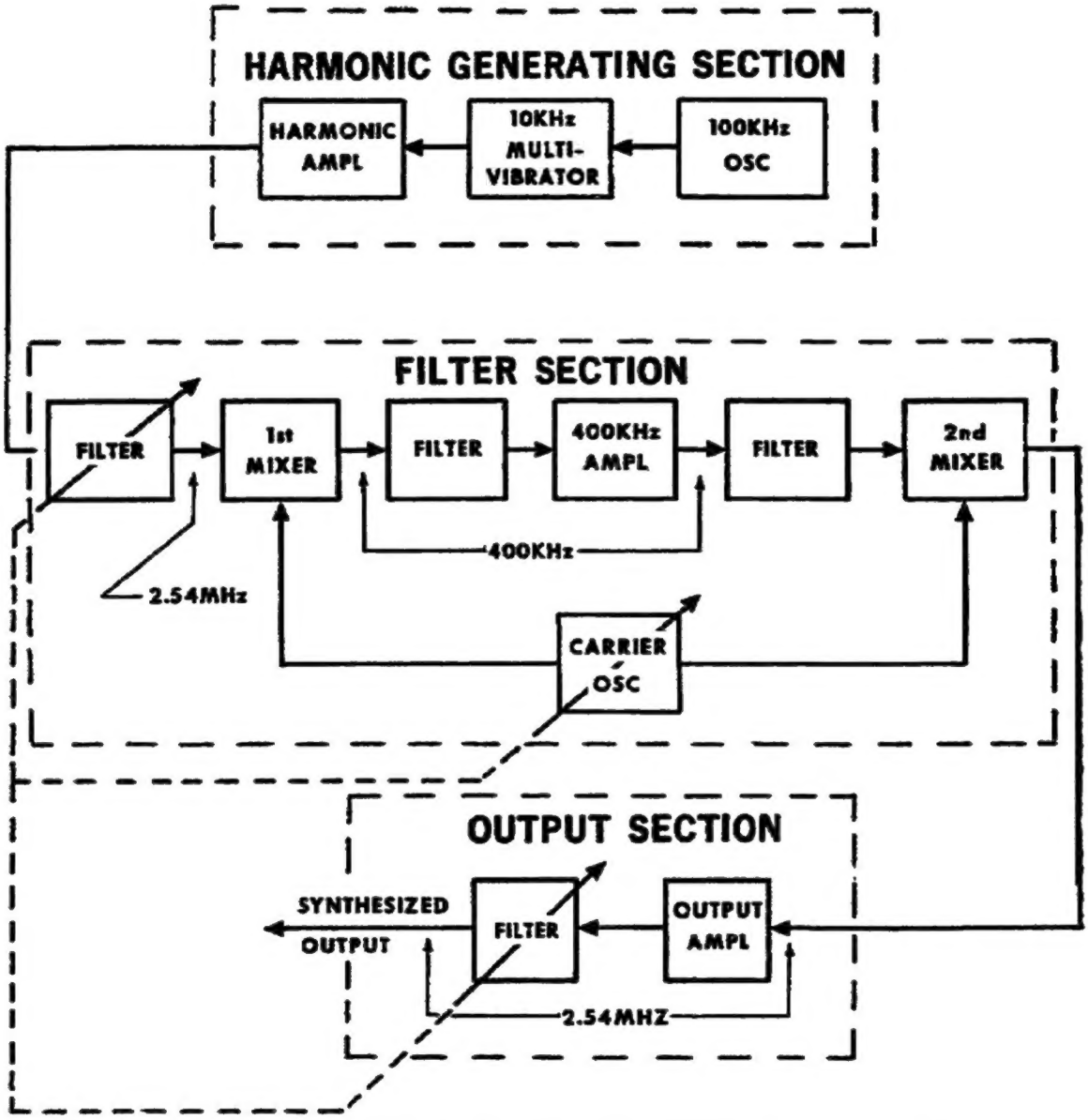

Figure 6. A synthesizing circuit using the heterodyne method.

1-8. WHY SYNTHESIZED OUTPUT SIGNALS MUST BE STABILIZED

a. As we said in paragraph 1, the signals used in communication systems must be exact and stable. Any variations in the frequency transmitted by one system can cause interference on another system. For example, it is common practice to transmit several hundred telephone channels over one radio channel. A ten percent variation in the radio channel output frequency band on one system can cause interference on some channels being transmitted by another system.

b. Since synthesizing circuits produce signals for communication systems, at least one of the synthesizing circuit oscillators must be very accurate. The most common and most accurate frequency controlling

device is a crystal. However, as stable as a crystal may be, there are still some variations. These variations are multiplied in the harmonic frequencies. Therefore, the higher the harmonic frequency selected as output frequency, the greater the variation in that frequency. For example, let's assume that a specific circuit produces multiple signals by harmonic generation. Assume also that a 100 kHz crystal controlled oscillator (often referred to as the master oscillator) supplies the signal from which the harmonic signals originate. Now, if this oscillator frequency output varies as little as 0.1 percent, the oscillator output frequency is between 99.9 and 100.1 kHz. That's a 200 Hz variation, which is well within certain acceptable standards. However the 100th harmonic of the original 100 kHz signal (10 MHz) varies between 9.99 and 10.01 MHz. That's a 20 kHz variation, which is far beyond an acceptable tolerance for many applications. Therefore, the master oscillator that supplies the signal input to the harmonic generator circuit must be stabilized. This oscillator, referred to as a stabilized master oscillator (SMO), is controlled not only by a crystal, but also by special frequency controlling circuits.

1-9. METHODS OF STABILIZING THE MASTER OSCILLATOR

a. There are several different ways to stabilize an oscillator, but the two most common methods are:

(1) Phase error detecting (phase lock).

(2) Temperature control.

b. The phase error, or phase lock method, shown by the block diagrams in figures 7 and 8 compares the phase of the output signal with one or more reference signals. The phase difference, if any, between the reference signal and output signal produces a dc error voltage. This error voltage is then applied to a reactance circuit that changes the reactance of the oscillator circuit. The error voltage determines if the reactance of the circuit is increased or decreased. This increase or decrease determines whether the output frequency is increased or decreased. In any case, the change is a corrective action, which continues until the phase difference is zero. In other words, this constant phase error checking holds the oscillator output frequency constant.

c. The temperature of the component parts of an oscillator circuit has a great effect on the oscillator's output frequency. Controlling the temperature of these component parts helps to control the accuracy and stability of the output signal. However, you need to control the temperature of only a few key items. These items are the crystal and the amplifying device (transistor or electron tube). You control the temperature by placing them in an inclosure called an oven. This oven can be a simple metal box, or it can be an elaborate insulated inclosure with temperature sensitive control circuits.

1-10. FREQUENCY ADD, SUBTRACT, MULTIPLY AND DIVIDE CIRCUITS

Most frequency synthesizing circuits are made up of several different types of circuits that either add, subtract, multiply, or divide the frequency of the signal applied to the input. Therefore, you'll see many block diagrams of synthesizing circuits that are designated with a mathematical symbol such as +, -, x, or ÷. Make sure that you know what type circuit each symbol designates by studying the explanations given below.

a. Add Circuit. A modulator and filter circuit combination that selects the upper sideband for the output. For example, if a 1 kHz and a 3 kHz signal is applied to the input of a modulator and a 4 kHz appears at the output, then this is an add circuit.

b. Subtract Circuit. A modulator and filter circuit combination that selects the lower sideband as the output. For example, if the input signals are 1 kz and 3 kHz, and the output signal is 2 kHz, it's a subtract circuit.

c. Multiply Circuit. Harmonic generating and filter circuit that selects one of the harmonic signals. For example, a circuit that selects a 100 kHz signal from a 10 kHz oscillator is a multiply by 10 circuit

d. Divide Circuit. This circuit can be one of two types:

(1) A harmonic generating and filter circuit that selects one of the subharmonics. That is, a circuit that produces a 50 kHz signal output, which is the 2d subharmonic from a 100 kHz oscillator, is a divide by two circuit. If the output were a 10 kHz signal from this oscillator it would make the circuit a divide by 10 circuit.

(2) A multivibrator, or combination of multivibrator circuits depending on the amount of division required. One multivibrator divides by two. Five multivibrators connected in series divides by 10, and so on.

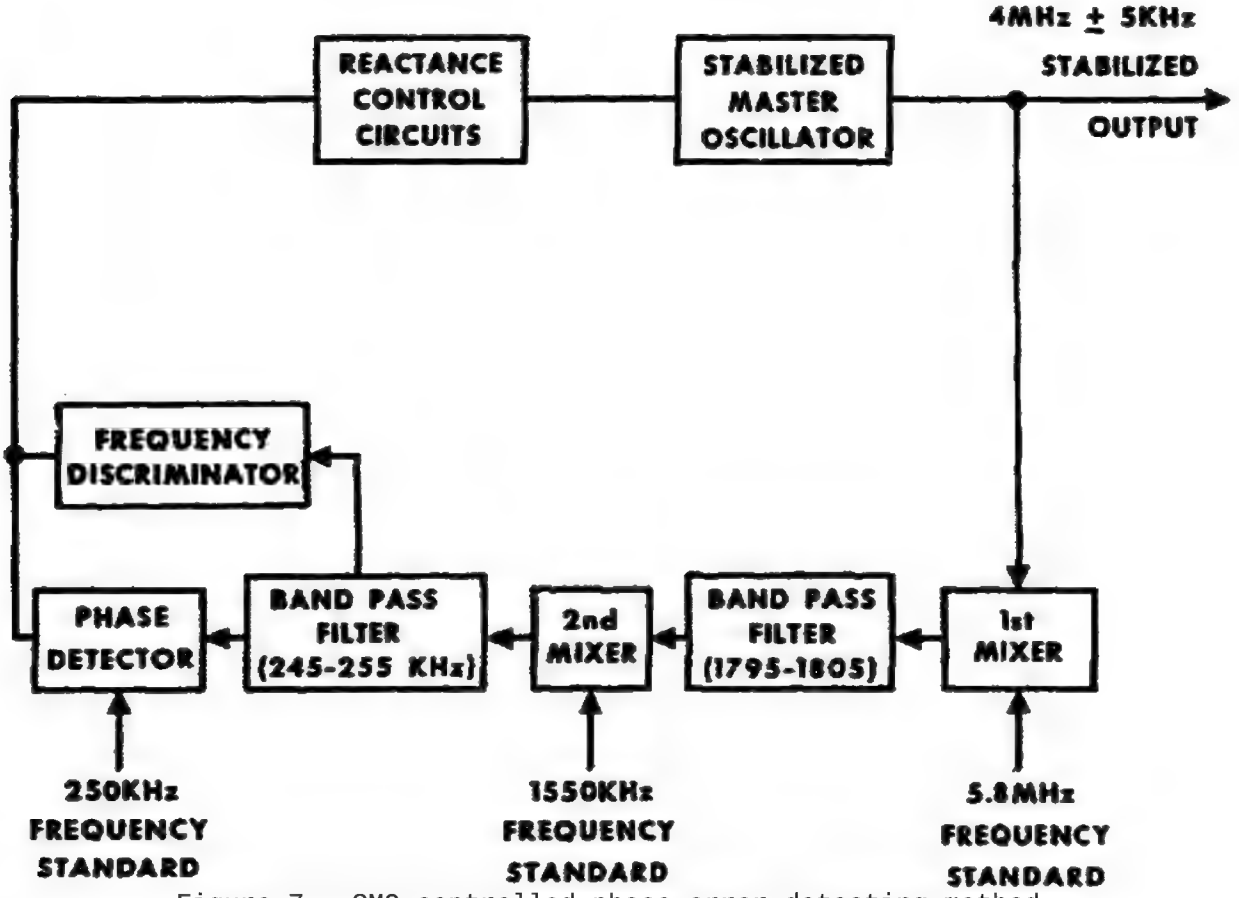

Figure 7. SMO controlled phase error detecting method.

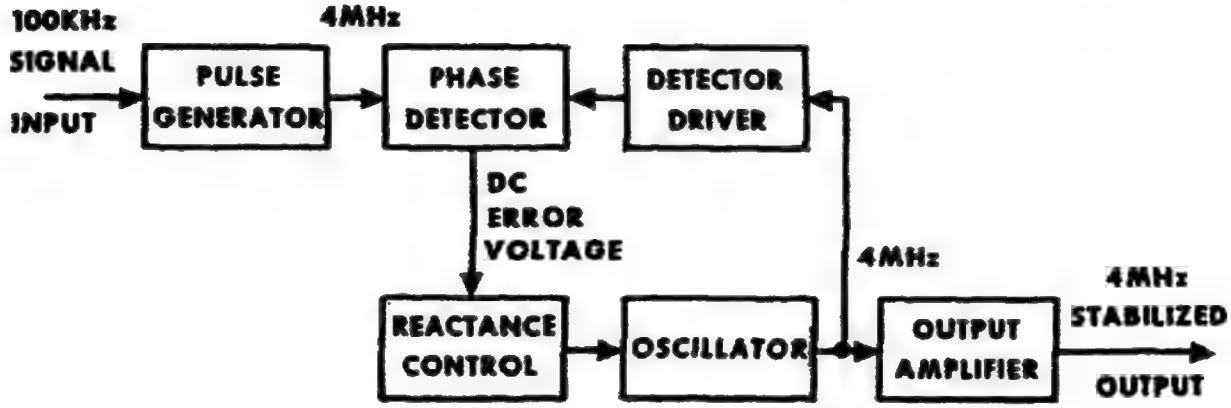

Figure 8. SMO phase lock controlled circuit.

STUDY EXERCISES

In each of the following exercises, select the ONE answer that BEST completes the statement or answers the question. Indicate your solution by circling the letter opposite the correct answer in the subcourse booklet.

1. Many current items of communication equipment contain frequency synthesizers. The function of a frequency synthesizer is to

   a. prevent radio interference.

   b. reduce radio interference by 10 percent.

   c. multiplex several hundred telephone channels.

   d. produce several frequencies from one frequency source or a minimum number of sources.

2. Assume that a 7-kHz signal is being modulated by a 300-Hz signal in an unbalanced modulator. What are the four output signal frequencies?

   a. 7 kHz, 3 kHz, 700 Hz, 300 Hz

   b. 7.3 kHz, 7 kHz, 6.7 kHz, 300 Hz

   c. 14 kHz, 7.3 kHz, 600 Hz, 300 Hz

   d. 7.3 kHz, 3.7 kHz, 700 Hz, 300 Hz

3. A balanced modulator with an input of 140 and 1,600 kHz will produce an output of

   a. 1,460 and 1,600 kHz.

   b. 1,460 and 1,740 kHz.

   c. 140, 1,400, 1,600, and 1,700 kHz.

   d. 140, 1,460, 1,640, and 1,740 kHz.

4. The synthesizing method most likely to be used to provide the carrier frequencies in a multichannel telephone system is the

   a. addition method.
   b. heterodyne method.
   c. basic modulation method.
   d. harmonic generation method.

5. The synthesizing method that produces a single synthesized signal is the

   a. heterodyne method.
   b. subtraction method.
   c. harmonic generation method.
   d. unbalanced modulator method.

6. What frequency synthesizing method is used if a harmonic and a noise-free signal is required?

a. Heterodyne method
c. Basic modulation method
b. Phase-lock method
d. Harmonic generation method

7. A common method of generating harmonics is to apply the fundamental frequency to a

a. fixed filter.
c. nonlinear device.
b. variable filter.
d. stabilized master oscillator.

8. Assume that the frequency of the input generator in the circuit shown in figure 3 of IT 51048 is changed from 4 kHz to 3 kHz. The harmonic filters would have to be changed to pass the output frequencies of

a. 3, 4, 6, and 8 kHz.

b. 3, 6, 9, and 12 kHz.

c. 6, 9, 12, and 15 kHz.

d. 6, 10, 14, and 18 kHz.

9. A multivibrator is a good source of a square-wave signal. One reason for using a square-wave signal source in a frequency synthesizer is to produce an output signal that is

a. free from noise.
c. rich in odd harmonics.
b. extremely stable.
d. rich in even harmonics.

10. The typical synthesizing circuit that uses the heterodyne method is divided in three sections. These three sections are the

a. 1st mixer, 2d mixer, and 400-kHz amplifier.

b. harmonic generating section, filter section, and output section.

c. harmonic amplifier section, 10-kHz multivibrator section, and 100-kHz oscillator section.

d. filter section, output amplifier section, and carrier oscillator section.

11. The output signal from the carrier oscillator is used in two stages of the heterodyne-type frequency synthesizer (fig. 6). These two stages are the

a. 400-kHz amplifier and second mixer.

b. first mixer and harmonic amplifier.

c. second mixer and tuned amplifier.

d. first mixer and second mixer.

12. The purpose of the filter section of the synthesizing circuit shown in figure 6 is to

a. generate odd harmonics.

b. stabilize the output signal.

c. select and purify the desired harmonic.

d. insure that the 400-kHz signal is fed to the output section.

13. Assume that you are analyzing the block diagram of the synthesizer shown in figure 6. The heterodyning process takes place in the

a. 400-kHz amplifier and the second mixer.

b. first mixer and the harmonic amplifier.

c. second mixer and the tuned filter.

d. first mixer and the second mixer.

14. One method of preventing variations in the output frequency of a radio transmitter is to replace its unstable oscillators with frequency synthesizers. The transmitter's output frequency must be exact and stable in order to

a. aid the operators.

b. minimize transmitter downtime.

c. prevent overcrowding of the frequency bands.

d. prevent one radio system from interfering with another system.

15. The most common and most accurate frequency-controlling device is a

a. crystal.

b. reactor.

c. transistor.

d. transformer.

16. The two most common methods of stabilizing an oscillator are the

a. linear and nonlinear methods.

b. heterodyne and filtering methods.

c. harmonic generation and filtering methods.

d. phase-lock and temperature control methods.

17. The block diagram shown in figure 7 illustrates the phase-error-detecting method of stabilizing the master oscillator. The circuit that changes the output frequency as the dc error voltage changes is the

a. 1st mixer.
c. bandpass filter.
b. 2d mixer.
d. reactance control.

18. When an oven is used in a frequency synthesizer, the circuit component that always appears within the oven is the

a. tuning capacitor.
c. multivibrator tube.
b. oscillator crystal.
d. amplifier transistor.

19. A modulator and filter circuit combination that selects the upper sideband for the output is

a. an add circuit.
c. a multiply circuit.
b. a divide circuit.
d. a subtract circuit.

20. A harmonic generating and filter circuit that selects one of the harmonic signals for the output is

a. an add circuit.
c. a multiply circuit.
b. a divide circuit.
d. a subtract circuit.

Check your answers with Lesson 1 Solution Sheet, pages 29 and 30.

LESSON 2

CLASSES OF SYNTHESIZERS

SCOPE.....Principles of direct and indirect synthesizers; simplified block diagram analysis of frequency synthesizers.

CREDIT HOURS.....2

TEXT ASSIGNMENT.....Attached Memorandum, para 2-1 thru 2-3

MATERIALS REQUIRED.....None

SUGGESTIONS.....None

LESSON OBJECTIVES

When you have completed this lesson, you should:

1. Know that the two main classes of frequency synthesizers are direct and indirect.

2. Know that the direct class furnishes a signal directly from a crystal-controlled oscillator.

3. Know that the indirect class furnishes a signal from a variable-frequency oscillator, which is indirectly stabilized by a crystal oscillator.

4. Know that the stability of the output signal from a direct-type frequency synthesizer depends upon the stability of all crystals used to develop the signal.

5. Know that the stability of the output signal from an indirect-type frequency synthesizer depends upon the stability of the reference crystal oscillator.

6. Know that a tactical radio set using a frequency synthesizer is normally a transceiver.

7. Be able to identify individual frequency synthesizers used with fixed station receivers and transmitters.

ATTACHED MEMORANDUM

2-1. CLASSES OF SYNTHESIZERS

A frequency synthesizer is seldom an individual item; it is normally part of a complete radio set. Occasionally, specialized frequency synthesizers are made available as individual items, but these are normally limited to special applications, such as for converting existing radio sets, or for

laboratory use. The principal function of a frequency synthesizer is to furnish all or most conversion frequencies needed by a radio set. A secondary function is to stabilize all operating frequencies furnished by the synthesizer. The simpler types of frequency synthesizers are usually found in tactical radio sets where space and weight are paramount factors. Further, frequency synthesizers in tactical radio sets normally serve these sets in transceiver configurations; that is, the frequency synthesizers furnish identical frequencies to the transmitter and receiver sections of the radio sets. Transceivers are designed for half-duplex operation, where each operator takes his turn at receiving or sending. In fixed-station equipment, the frequency synthesizers are far more sophisticated. Moreover, fixed-station operation normally calls for frequency synthesizers having identical stability and frequency increment characteristics for transmitters and receivers. This arrangement permits wide separation of the transmitters and receivers, using different frequencies for transmission and reception. This combination allows full-duplex operation where each station is capable of sending and receiving simultaneously. For convenience, we will classify synthesizers as direct and indirect. The direct class furnishes a signal directly from a crystal-controlled oscillator or from a combination of two or more crystal oscillators. The output frequency is obtained by combining the outputs of the several oscillators in a mixing and frequency-selecting circuit. The indirect class derives a signal from a variable-frequency oscillator (VFO), which is indirectly stabilized by a crystal oscillator or a combination of crystal oscillators. In practice the classifications of direct and indirect are unimportant, since circuit design sometimes incorporates significant features of both types.

a. Direct. In direct frequency synthesis, the frequencies of one or more crystal oscillators are divided, multiplied, and added to produce the desired output, while undesired output frequencies are attenuated by fixed or variable filters. A great number of frequencies can be produced, each related by an exact predetermined ratio to the highly stable crystal oscillators. Since the stability of any selected output frequency depends entirely on the stability of the various crystals, great care usually goes into the preparation of these crystals. The most favorable frequency for each crystal is chosen, and the crystal is ground to a precise frequency. The entire crystal assembly is then enclosed in an oven controlled by a complex circuit, so as to maintain nearly uniform temperature. Although direct synthesis is a more straightforward method of generating the desired frequency, the elimination of spurious frequencies in this method is difficult.

b. Indirect. In an indirect system, a VFO is locked by a control loop, containing a frequency discriminator and a phase detector, to a signal derived from a crystal-controlled frequency standard. As in the direct method, the crystals are enclosed in a temperature-stabilizing oven. The control loop performs an automatic frequency control (AFC) function so as to stabilize the output frequency at any setting of the VFO frequency-selecting control knob. Thus any selected frequency within the range of the VFO will be stabilized by the AFC feedback circuit. However, the output frequency is not firmly locked by the crystal-controlled frequency standard, nor is the output frequency determined by the crystal oscillator. The VFO determines its own output frequency, but it references on the crystal oscillator to benefit from the inherent stability of the crystal or crystals.

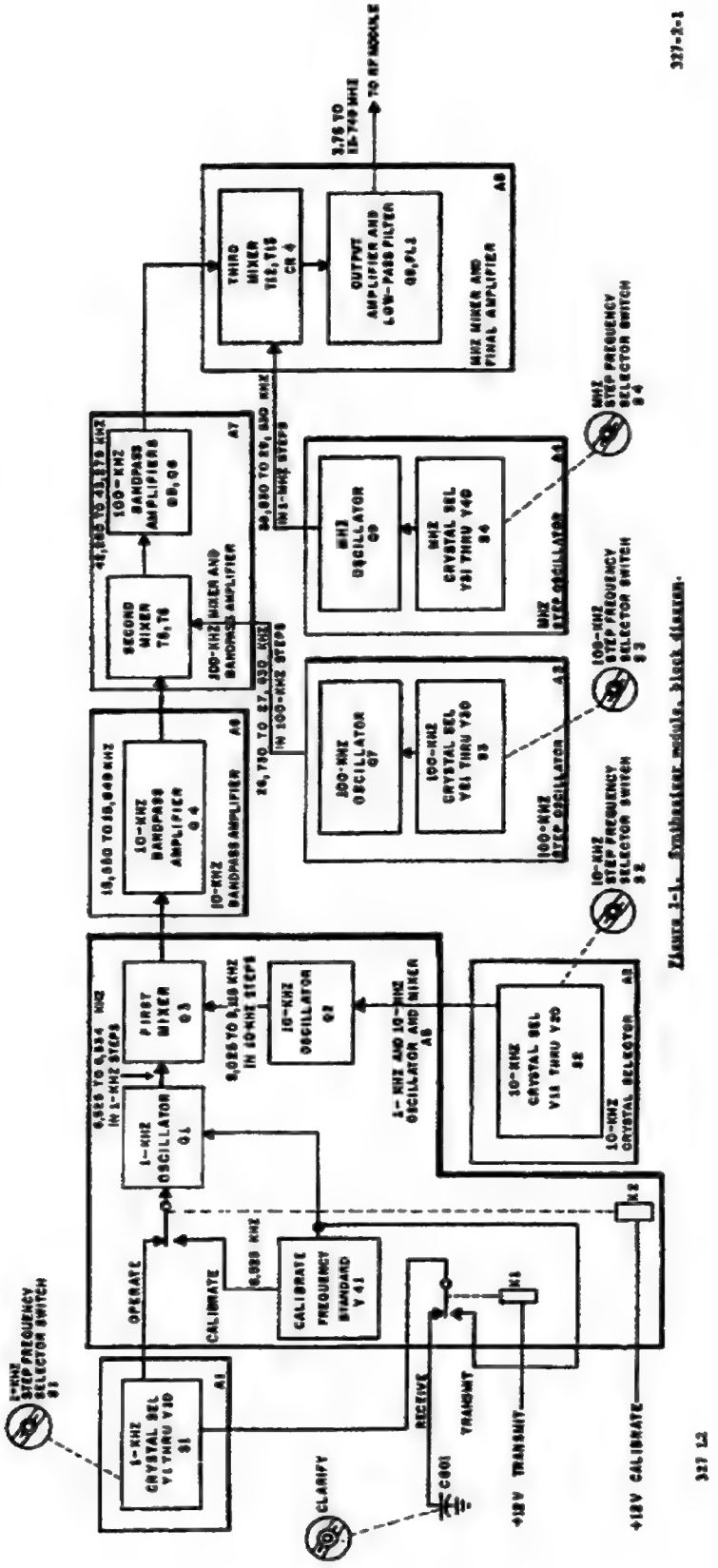

Figure 2-1. Synthesizer module, block diagram.

2-2. DIRECT-TYPE SYNTHESIZER BLOCK-DIAGRAM ANALYSIS

To illustrate one type of frequency synthesizer for tactical use, we will make a block-diagram analysis of a direct-type synthesizer.

a. Synthesizer Operation. The synthesizer module of Radio Set AN/PRC-74 shown in figure 2-1 consists of assemblies A1 through A9. The combination of these assemblies provides a series of crystal-controlled oscillators, mixers, bandpass filters, and amplifiers to generate a selectable output signal in the range of 3.75 to 13.749 MHz. The selectable output signal frequency is always 1,750 kHz above the RF signal selected by the radio set for operation. Thus the operating range of the radio set is 2.0 to 11,999 MHz. The 1-kHz step frequency selector switch, S1, 10-kHz step frequency selector switch S2, 100-kHz step frequency switch S3, and MHz frequency selector switch S4 select a crystal for each of their respective oscillator circuits. All selector switches and controls necessary for synthesizer operation are located on the front panel. Since this is a direct type of frequency synthesizer, all frequencies are generated by crystal oscillators.

b. Crystal Assemblies. Crystals with their step frequency selecting switches are located on assemblies A1, A2, A3, and A4. Assemblies A3 and A4 also contain the oscillator circuits associated with their crystals. The two oscillators for the crystals in assemblies A1 and A2 are located on assembly A5. The step frequency switch positions and corresponding frequencies are shown in table I below. The frequency labels on the oscillator controls may give the impression that the output frequencies are 1, 10, and 100 kHz. This is not the case; the frequencies generated by the oscillators appear in increments of those values.

TABLE I
OSCILLATOR FREQUENCIES

Switch position (digit)	OSCILLATOR FREQUENCIES (kHz)			
	1 kHz (Q1)	10 kHz (Q2)	100 kHz (Q7)	MHz (Q9)
0	6,525	9,025	26,730	------
1	6,526	9,035	26,830	------
2	6,527	9,045	26,930	38,530
3	6,528	9,055	27,030	37,530
4	6,529	9,065	27,130	36,530
5	6,530	9,075	27,230	35,530
6	6,531	9,085	27,330	34,530
7	6,532	9,095	27,430	33,530
8	6,533	9,105	27,530	32,530
9	6,534	9,115	27,630	31,530
10	------	------	------	30,530
11	------	------	------	29,530

(1) The 1-kHz oscillator, Q1, generates a frequency from 6,525 to 6,534 kHz in l-kHz steps.

(2) The 10-kHz oscillator, Q2, generates a frequency from 9,025 to 9,115 kHz in 10-kHz steps.

(3) The 100-kHz oscillator, Q7, generates a frequency from 26,730 to 27,630 kHz in 100-kHz steps.

(4) The MHz oscillator, Q9, generates a frequency from 29,530 to 38,530 kHz in 1,000-kHz or 1-MHz steps.

NOTE: Further references to these oscillators will be made by their Q numbers (Q1, Q2, Q7, Q9).

c. First Frequency Translation. The output of oscillator Q1 is applied to first mixer Q3 where it is mixed with the output of oscillator Q2. The first mixer output is the sum of the l-kHz and the 10-kHz oscillator signals. The output of the mixer is applied to 10-kHz bandpass amplifier Q4. The sum of any two selected frequencies in the 1 kHz and 10 kHz columns in table I fall within the 15,550-to 15,649-kHz bandpass of the amplifier. This amplifier has tuned circuits (filters) that select the sum frequencies within the 10-kHz pass band and reject undesired frequencies and harmonics (spurious frequencies) that result from the heterodyning process.

d. Second Frequency Translation. Output signals of the 10-kHz bandpass amplifier are applied as one of the inputs to the second mixer, T5, T6. The 100-kHz signal from oscillator Q7 is applied to the second mixer as the second input signal. The output of the second mixer is applied to 100-kHz bandpass amplifiers Q5 and Q6. This amplifier assembly uses filters to extract the sum frequencies and suppresses the remaining frequencies developed by the heterodyning process. The sum of any three selected frequencies from the 1 kHz, 10 kHz, and 100 kHz columns in table I falls within the 42,280-to 43,279-kHz bandpass of the 100-kHz amplifier.

e. Third Frequency Translation. The output signal of the 100-kHz bandpass amplifier is supplied as one input to the third mixer. The output of oscillator Q9 is supplied as the second input to the third mixer. The difference of the two input signals is selected by the output amplifier and low-pass filter, which also attenuates the spurious frequencies and unwanted sidebands resulting from the heterodyning process. The subtraction of any number in the Hz column in table I from the sum of any three numbers in the 1 kHz, 10 kHz, and 100 kHz columns yields a frequency that falls within the 3,750-to 13,749-kHz pass band of the low-pass filter of the output amplifier. Two switch positions in the MHz column are not used; neither are two positions in the 1 kHz, 10 kHz, and 100 kHz columns. The output of filter FL1 (3.750 to 13.749 MHz) is the range of the synthesized frequencies. This synthesizer therefore obtains 10,000 frequencies in increments of 1 kHz from a total of 40 crystals.

f. Frequency Stability. In this synthesizer, four crystals are always used to obtain one output frequency. Instability in any one or more of these crystals causes a comparable variation in output frequency. To compensate for this variation, capacitor C601 is placed in series with the selected crystal in assembly Al during receiving. The receiving operator varies the C601 to obtain the best quality signal; therefore the label CLARIFY. Capacitor C601 is automatically removed from the circuit during transmission by the action of relay K1.

g. Calibration. An adjustable capacitor is wired in parallel with each crystal in assembly Al for minor frequency adjustment. To make this adjustment, a frequency standard is required. Crystal Y41 (6,525 kHz) establishes a reference frequency for this purpose. The crystal is applied to oscillator Q1 by relay K2. Normal operation of the synthesizer is disabled during the calibration process.

h. Operation. To select the output frequency of the radio set, the operator merely selects the desired frequency by means of the four step frequency selector controls in the frequency synthesizer. For example, assume the radio output frequency to be 3,167 kHz, of 3.167 MHz. The operator will set his step frequency selector controls as follows:

Control	Setting
MHz	3
100 kHz	1
10 kHz	6
1 kHz	7

(1) Table I shows that the frequency for switch position 7 in the 1 kHz column is 6,532 kHz.

(2) Frequency for switch position 6 in the 10 kHz column is 9,085 kHz.

(3) Frequency for switch position 1 in the 100 kHz column is 26,830 kHz.

(4) The sum of these frequencies is 42,447 kHz.

(5) The difference between 42,447 and 37,530 is 4,917 kHz. This is the output frequency of the synthesizer.

(a) During reception, the incoming frequency of 3,167 kHz heterodynes with the synthesizer output frequency of 4,917 kHz in a balanced modulator in the RF module (not shown in figure 2-1). The resultant difference of 1,750 kHz is the intermediate frequency (IF) required by the IF-audio module in the radio set.

(b) During transmission, the outgoing IF signal of 1,750 kHz from the IF-audio module heterodynes with the synthesizer output frequency of 4,917 kHz in the balanced modulator of the RF module. The resultant difference frequency of 3,167 kHz is the output signal of the transmitter.

2-3. INDIRECT-TYPE SYNTHESIZER BLOCK DIAGRAM ANALYSIS

(fig. 2-2)

To illustrate one type of frequency synthesizer of fixed-station use, we will make a block diagram analysis of Frequency Stabilizer Kit SBM-1102. The SBM-1102 consists of two units, a frequency stabilizer (A) and an electrical and frequency synthesizer (B). It is used as an improvement modification for Radio Receiving Set AN/FRR-41. The AN/FRR-41 is a fixed-station dual-diversity radio receiving system, which consists of two Radio Receivers R-390A/URR and two Single-Sideband Converters CV-157A/URR. The SBM-1102 is used to increase the accuracy and versatility of the receiving system. The frequencies it provides are far more stable than the internal frequencies generated by the receivers and converters. Stability of internal frequencies allows more accurate heterodyning of the intelligence signal. The SBM-1102 allows fast, easy tuning to the received signal. It can even be used with an unsynthesized transmitter. If the transmitter drifts slightly from its operating frequency the receiver can quickly be retuned to the new frequency.

a. Synthesizer Operation. Frequency Stabilizer Kit SBM-1102 does not affect the received intelligence signals in any way. It is connected in parallel with the receivers and converters in the receiving system. The received signal is fed from the antenna through the receivers and converters to the multiplex equipment. Thus, the received signal path remains the same even with the SBM-1102 installed. The only difference is that now the receivers and converters are being supplied with highly stable frequencies from the SBM-1102 and operate with extreme accuracy.

b. Relay Control Voltage. The +28 relay control voltage determines whether the AN/FRR-41 uses its own internal frequencies for signal conversion or those provided by the SBM-1102. When the SBM-1102 is installed in the AN/FRR-41, the original oscillators in the receivers and converters are not removed; they are connected through relay circuitry to the same points they were before. The output frequencies of the SBM-1102 are connected to the same relay circuitry. If the relays are energized, they disconnect the AN/FRR-41 oscillators and connect replacement frequencies from the SBM-1102. If the relays are deenergized, the SBM-1102 is disconnected, and the AN/FRR-41 is connected to its own oscillators for its mixer frequencies. Should equipment difficulties develop in the synthesizer or stabilizer during stabilized operation, the receiver and converters can be returned to normal operation with negligible downtime while repairs are being made.

c. Reference Frequencies. To generate the five frequencies required by the AN/FRR-41 receiving system, the SBM-1102 uses a single, highly stable 1-MHz signal. It generates the other frequencies by phase-locking other oscillators to the 1-MHz signal. The 1-MHz RF oscillator subassembly (A5) is located in the stabilizer (fig. 2-2). The oscillator is called a pullable

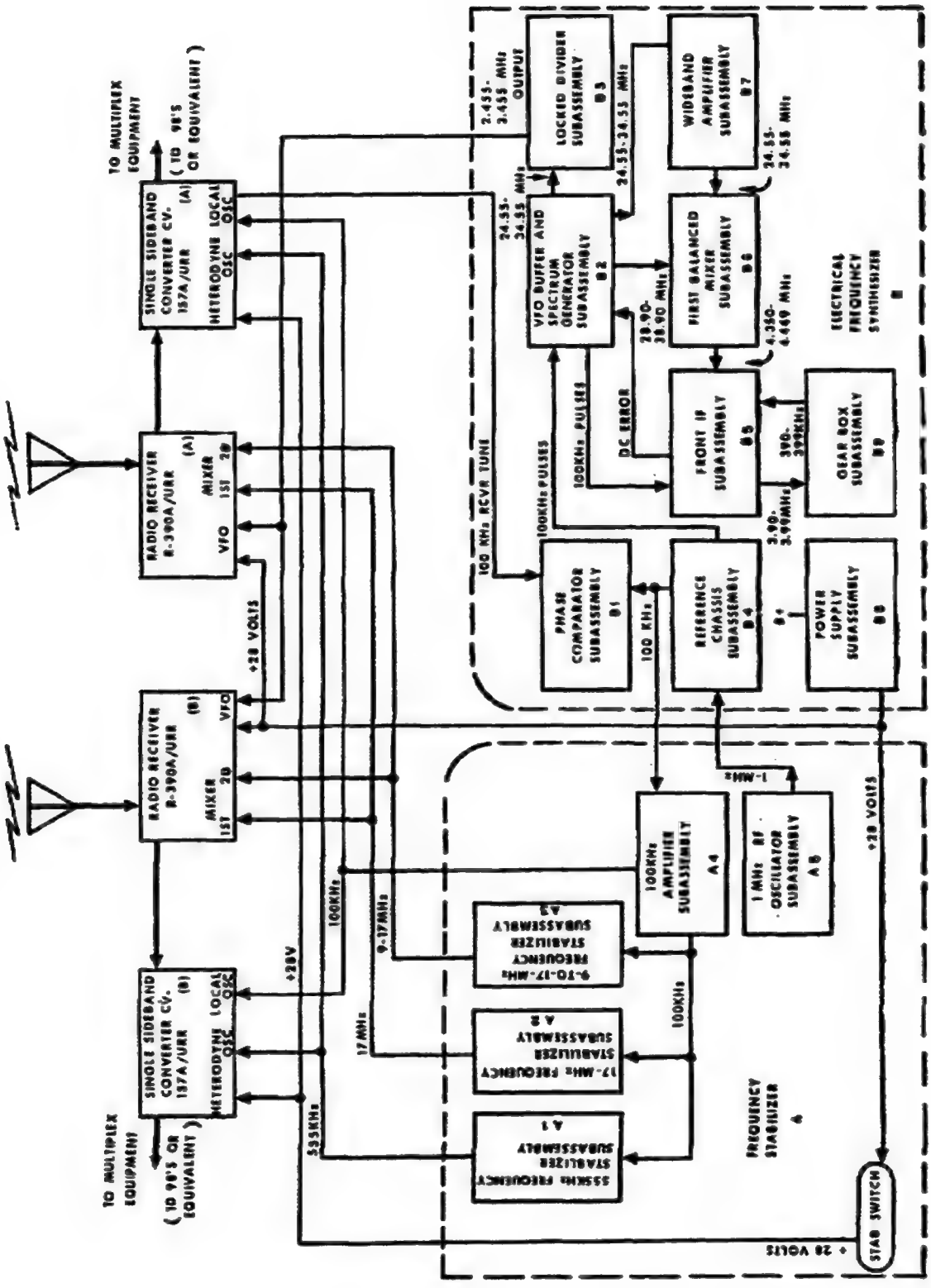

Figure 2-2. AN/FRR-41 modified by SBM-1102, simplified block diagram.

oscillator, which means that it is manually adjustable, or tunable. This allows the entire receiver system to be tuned to the frequency being received if the transmitter drifts. The 1-MHz signal is connected to the reference chassis subassembly (B4) in the synthesizer. This assembly divides the frequency and puts out a 100-kHz signal to three other subassemblies. The tuning accuracy of the receiver system is determined by comparing the phases of the 100-kHz received carrier frequency and the stable 100-kHz internal reference frequency in the phase comparator subassembly (B1). The resultant output is a varying dc voltage whose change is proportional to the phase difference of the two signals. This dc voltage is fed to a panel-mounted zero-center-scale meter.

d. Output Frequencies.

(1) The 100-kHz signal from the reference chassis subassembly (B4) is fed to the 100-kHz RF amplifier subassembly (A4) in the stabilizer. The amplified signal is then sent to the two converters of the AN/FRR-41 and is also coupled to three subassemblies in the stabilizer. Starting with the highly stable 100-kHz signal as a reference, the 555-kHz stabilizer subassembly (A1) produces an equally stable 555-kHz output frequency that is coupled to the converters. In the same manner, the 17-MHz stabilizer subassembly (A2) produces a 17-MHz output signal. Notice, however, that this signal is coupled to the two receivers as is the output of the subassembly (A3). The reference frequency produced by the 9-17 MHz stabilizer subassembly (A3) is variable from 9 MHz to 17 MHz. Its frequency selection is controlled by the MHz change switch on the stabilizer drawer.

(2) The reference chassis subassembly (B4) in the synthesizer also produces a 100-kHz reference frequency that is coupled to the variable frequency oscillator (VFO) buffer and spectrum generator subassembly (B2). There are many outputs from this subassembly. The actual synthesizer output signal is derived from the 24.55-34.55 MHz shown leaving the right side of the block. This variable frequency is divided into a 2.455-3.455 MHz output frequency by locked divider subassembly (B3) and is amplified and fed to the two receivers. This reference frequency, more than any other, determines the stability of the receiver because it replaces the VFO in the receiver. If it is unstable the receivers will be unstable.

(3) The frequency of the VFO (B2) is controlled by a dc error voltage produced by subassemblies B7, B6, B5, and B9 in the following manner: 24.55-34.55 MHz signal is coupled from the VFO buffer and spectrum generator subassembly (B2) to the wideband amplifier subassembly (B7). The amplified signal is then mixed in the first balanced mixer subassembly (B6) with a 28.90-to 38.90-MHz signal produced by subassembly B2. The mixer output is in the band between 4.350 and 4.449 MHz. The front IF subassembly (B5) in conjunction with the gear box subassembly (B9) produces a stable reference frequency of 390 to 399 kHz. This is done by multiplying and dividing the output of an oscillator and phase-locking it to the 100-kHz pulses which the VFO (B2) generates from the highly stable

100-kHz reference frequency. Also, the front IF subassembly (BS) mixes the 4.350- to 4.449-MHz signal (from subassembly 36) with another oscillator frequency. It, too, is phase locked to a multiple of the same 100-kHz pulses we have just discussed. From this, another 390-to 399-kHz frequency is developed. The two nearly identical but separate frequencies of 390 to 399 kHz (one from the reference frequency and the other from the VFO output frequency) are compared by a discriminator in subassembly B5. If a frequency or phase difference exists, an error voltage is developed and applied to the VFO (B2).

STUDY EXERCISES

In each of the following exercises, select the ONE answer that BEST completes the statement or answers the question. Indicate your solution by circling the letter opposite the correct answer in the subcourse booklet.

1. The primary function of a frequency synthesizer is to furnish all or most conversion frequencies needed by a radio set. A secondary function is to

   a. regulate all voltages in the radio set.

   b. attenuate all noisy frequencies received by the radio set.

   c. provide additional amplification of weak signals when needed.

   d. stabilize all operating frequencies furnished by the synthesizer.

2. A frequency synthesizer is often used in a transceiver to

   a. disable the radio transmitter during reception.

   b. disable the radio receiver during transmission.

   c. allow both the transmitter and the receiver to operate at the same time.

   d. furnish identical conversion frequencies to the receiver and the transmitter.

3. The output signal of the indirect-class synthesizer is derived from a

   a. crystal oscillator.

   b. stabilized master oscillator.

   c. variable-frequency oscillator.

   d. combination of crystal oscillators.

4. Assume that the step frequency selectors of the synthesizer module of Radio Set AN/PRC-74 are set as follows: S1 at 2, S2 at 3, S3 at 4, and S4 at 5. The output frequency from the synthesizer is

a. 8,932 kHz.
c. 3,682 kHz.
b. 7,182 kHz.
d. 1,750 kHz.

5. How many crystals are used by the synthesizer module of Radio Set AN/PRC-74 to provide frequencies in the range of 3.750 to 13.749 MHz in increments of 1 kHz?

a. 10
c. 40
b. 20
d. 100

6. In all frequency calculations involving the frequency synthesizer of the AN/PRC-74, there is a factor of 1,750 kHz to consider. This frequency is the

a. difference between the synthesizer output frequency and calibration crystal Y41.

b. sum of the synthesizer output frequency and the IF of the IF-audio module.

c. difference between the synthesizer output frequency and the operating frequency.

d. sum of the synthesizer output frequency and the operating frequency.

Exercises 7 through 10 are based on the block diagram of the synthesizer of Radio Set AN/PRC-74 (fig. 2-1).

7. In the block diagram of the frequency synthesizer of Radio Set AN/PRC-74, one assembly contains neither crystals nor mixers. That assembly is

a. A3.
c. A6.
b. A4.
d. A7.

8. During system operation, slight variations from the assigned receive frequency may be compensated for by the receiving operator by adjusting Capacitor

a. C601
c. C612.
b. C602.
d. C617.

9. The third mixer has two input signals, one from the MHz oscillator (Q9) and the second from the 100-kHz bandpass .amplifier. The signal selected by the output amplifier and low-pass filter is the

a. sum of the two input signals.

b. product of the two input signals.

c. quotient of the two input signals.

d. difference of the two input signals.

10. The output frequency of the second mixer (T5, T6), shown in assembly A6 of figure 2-1, is the sum of the output signals of oscillators

a. Q1 and Q2.

b. Q4 and Q7.

c. Q1, Q2, and Q7.

d. Q1, Q2, Q3, and Q7.

11. The intermediate frequency (IF) of Radio Set AN/PRC-74 must be heterodyned with the output signal of the frequency synthesizer to produce the transmitter output signal. What will the transmitter output frequency be if the output of the frequency synthesizer is 4,850 kHz?

a. 2,425 kHz

b. 3,100 kHz

c. 4,850 kHz

d. 6,600 kHz

SITUATION

Frequency Stabilizer Kit SBM-1102 is a combination of a frequency stabilizer section and a frequency synthesizer section. It was designed as an improvement modification for Radio Receiving Set AN/FRR-41.

Exercises 12 through 20 are based on this situation.

12. The difference between the frequencies provided by the SBM-1102 and the internal frequencies of the AN/FRR-41 is that the SBM-1102 frequencies are

a. unstabilized.

b. highly stable.

c. frequency modulated.

d. amplitude modulated.

13. Assume that you are operating a Radio Receiving Set AN/FRR-41 that has been modified by Frequency Stabilizer Kit SBM-1102. The effect that this modification will have is that the received intelligence signals will be

a. greatly distorted.

b. slightly distorted.

c. unaffected in any way.

d. converted into dc pulses.

14. The SBM-1102 is used as an improvement modification to the AN/FRR-41, since it increases its

a. bandwidth.
c. channel capacity.

b. sensitivity.
d. frequency stability.

15. The frequencies generated by the SBM-1102 are connected to the AN/FRR-41 system through the use of

a. relays.
c. transformers.

b. transistors.
d. coaxial cable.

16. The phase comparator subassembly (B1, fig. 2-2) determines the accuracy of the receiver system by comparing the 100-kHz received carrier frequency with the highly stable

a. 17-MHz frequency.

b. 390- to 399-kHz frequency.

c. 100-kHz reference frequency.

d. 2.455- to 3.455-MHz output frequency.

17. How does the operator know when he has selected the right conversion frequencies for the signal being received?

a. The fine tuning control is set at midpoint of its scale.

b. The output voltage developed by the phase comparator is zero.

c. The frequency counter shows the frequency of the signal that the receiver is receiving.

d. The reference oscillators are synchronized to precisely the same frequency and phase.

18. The reason for having a manually adjustable reference frequency in this kit is to compensate for

a. change in oven temperature.

b. transmitter frequency drift.

c. drift of receiver conversion frequencies.

d. aging of the reference oscillator crystal.

19. The oscillator that can be manually tuned if there is a drift in the received signal is the

a. 100-kHz oscillator.
c. 1-MHz RF oscillator.

b. 555-kHz oscillator.
d. 9- to 17-MHz oscillator.

20. The 2.4-MHz to 3.4-MHz frequency generated by the SBM-1102 (fig. 2-2) more than any other frequency determines the stability of the receivers because it replaces each receiver's

a. antenna system.

b. 28-volt power supply.

c. intermediate frequency (IF).

d. variable-frequency oscillator (VFO).

Check your answers with Lesson 2 Solution Sheet, pages 31 and 32.

HOLD ALL TEXT AND MATERIALS FOR USE WITH EXAMINATION.

SOLUTIONS

SUBCOURSE 327.....Frequency Synthesis

LESSON 1.....Introduction to Frequency Synthesis

All references are to the attached memorandum.

1. d--para 2

2. b--para 3, 5

Two original frequencies are 7 kHz and 300 Hz.

Sum frequency is 7 kHz plus 300 Hz, or 7.3 kHz.

Difference frequency is 7 kHz minus 300 Hz, or 6.7 kHz.

3. b--para 3, 5

There are two output signals from a balanced modulator, the upper and lower sidebands.

Sum frequency is 1,600 plus 140 kHz, or 1,740 kHz.

Difference frequency is 1,600 minus 140 kHz, or 1,460 kHz.

4. d--para 4b

5. a--para 4a(3)

6. a--para 4b

7. c--para 6a

8. c--para 6a

9. c--para 6c

10. b--para 7b, fig. 6

11. d--para 7c, fig. 6

12. c--para 7c

---

13. d--para 7c, fig. 6

14. d--para 8a

15. a--para 8b

16. d--para 9a

17. d--para 9b

18. b--para 9c

19. a--para 10a

20. c--para 10c

SOLUTIONS

SUBCOURSE 327.....Frequency Synthesis

LESSON 2.....Classes of Synthesizers

All references are to the attached memorandum.

1. d--para 2-1

2. d--para 2-1

3. c--para 2-1

4. b--para 2-2a, h, table I

Synthesizer output frequency = the sum of the output frequency of oscillators Q1, Q2, and Q7 minus the output frequency of Q9.

Q1 (S1 position 2) plus Q2 (S2 position 3) plus Q7 (S3 position 4)

= 6,527 + 9,055 + 27,130 - 42,712 kHz.

Q9 (S4 position 5) - 35,530 kHz.

Output frequency = 42,712 - 35,530 = 7,182 kHz.

5. c--para 2-2e

6. c--para 2-2h(5)

7. c--fig. 2-1

8. a--para 2-2f, fig. 2-1

9. d--para 2-2e, fig. 2-1

10. c--para 2-2d, fig. 2-1

11. b--para 2-2a, h(5)(b)

Transmitter output frequency = synthesizer output frequency
minus IF signal
= 4,850 kHz minus 1,750 kHz = 3,100 kHz

12. b--para 2-3

13. c--para 2-3a

14. d--para 2-3a

15. a--para 2-3b

16. c--para 2-3c

17. b--para 2-3c

18. b--para 2-3c

19. c--para 2-3c

20. d--para 2-3d(2)